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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

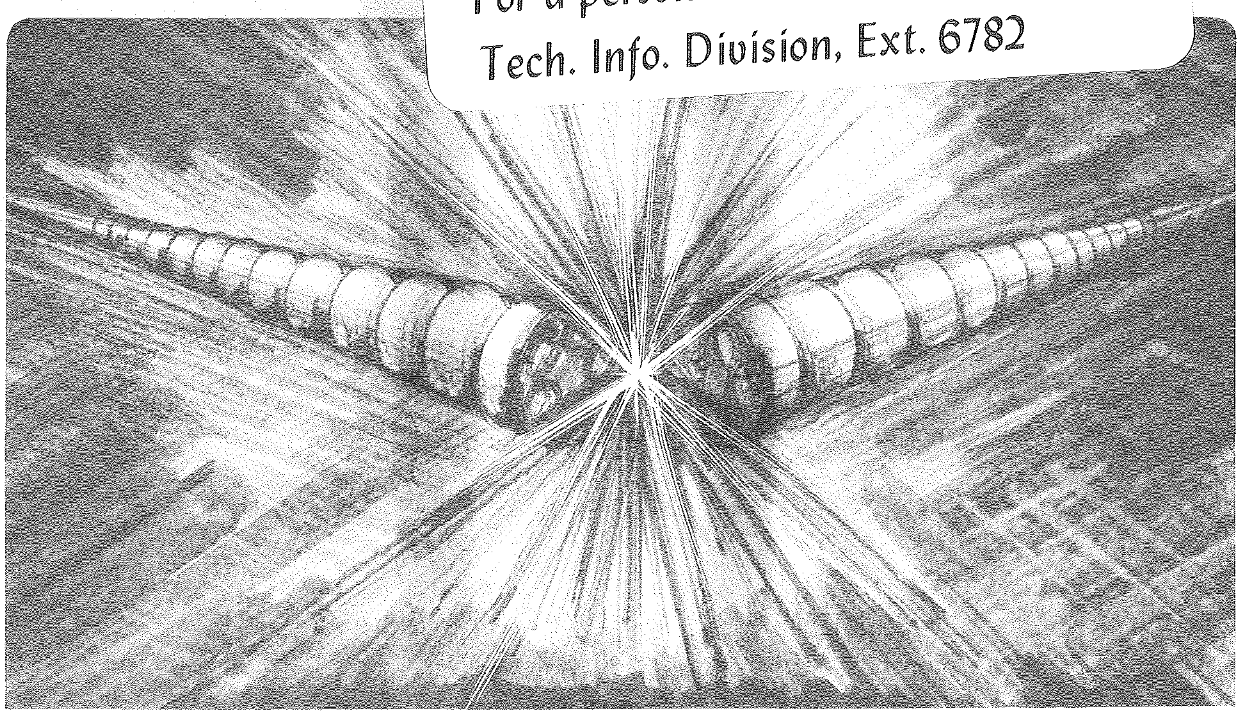
Accelerator & Fusion Research Division

HEAVY ION FUSION HALF-YEAR REPORT

October 1, 1980 - March 31, 1981

H.I.F. Staff

April 1981



Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

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This work was supported by the Director, Office of Energy Research, Office of Inertial Fusion, Research Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

CONTENTS

HIGHLIGHTS

- The Cs^+ pulsed drift tube injector has continued to operate satisfactorily in a program of studying the characteristics of the beam and of developing diagnostic tools.
- A single beam transport experiment has been designed and fabrication of the components has begun. The purpose of the experiment is the study of transverse beam dynamics and the stability of a space-charge dominated beam traveling through a periodic strong-focussing channel.
- Increasing attention has been given to multiple-beam heavy ion induction linacs and it appears that there will be significant technical and cost advantages in such a system.
- Theoretical studies of the longitudinal stability of beams and of longitudinal-transverse coupling have continued. Electrostatic quadrupole beam transport systems have also been an object of study.
- Engineering development of module components has included experiments with novel ignitrons as well evaluations of standard ones. Evaluation of magnetic core material also continues.

A. EXPERIMENTAL RESEARCH AND DEVELOPMENT ACTIVITIES

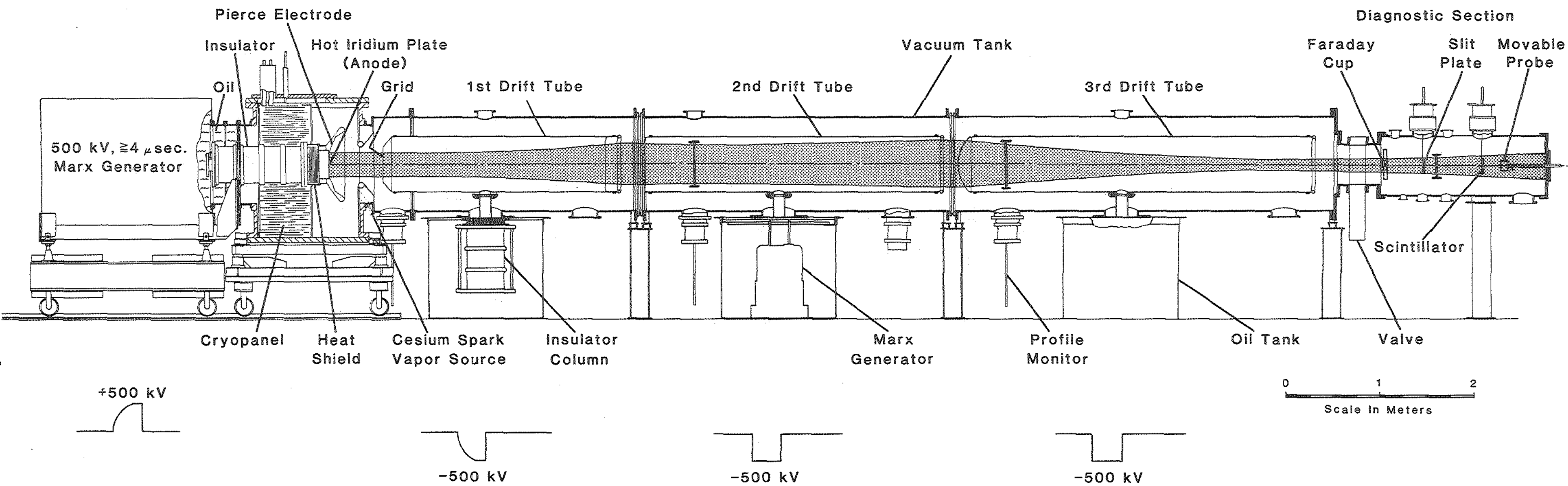
1. Cs^+ Pulsed Drift Tube Injector

The construction and assembly of the Cs^+ ion injector consisting of a pulsed source and 3 pulsed drift tubes has been complete since the middle of 1980. The measurement program, underway since then to characterize the beam, has been interspersed with the development of diagnostic equipment. The Cs^+ contact ionization source and each of the 3 drift tubes are driven by 500 kV Marx generators.

The space charge limited diode and drift tube acceleration system were designed with the aid of the EGUN code of Herrmannsfeldt. Measurements of the beam envelope have been made by means of a movable biased charge collector. Good agreement with the EGUN calculation is found. Measurements of the beam emittance have been made at the exit of the third drift tube. The normalized emittance $\pi\, \epsilon_N = 2 \times 10^{-6}\ \pi$ m-rad is better than required for further acceleration and transport in a Heavy Ion Fusion (HIF) Induction Linac Driver. The system is shown schematically in Fig. 1 along with the calculated and measured beam envelope profiles.

The system has been in routine operation at 300 kV/stage, giving a beam of 1.2 MeV Cs^+ with a total current of 355 mA in a 2.6μs pulse, which is the expected space charge limited current at that voltage and with the present grid structure. The pulse repetition rate is 1/4 Hz. About 10^5 pulses have been accumulated. In an electrostatically focussed system at the space charge limit there is only one solution to the beam dynamics, with the exception of source temperature effects which are insignificant here, and therefore the beam envelope and particle trajectory may be measured at any voltage.

The main effort over the past half year has been to develop reliable diagnostics to measure the beam envelope, total current, and emittance. In



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1 AMPERE Cs^{+1} PULSED DRIFT TUBE INJECTOR

Figure 1

addition, tests have shown that the goal of 500 kV/stage is achievable.

2. Experimental Program

Now that the injector is completely assembled and running we plan to use it for the following tasks:

- Measure gas desorption by heavy ion beam impact on surfaces at normal and glancing incidence.
- Reduce cesium consumption by optimizina the cesium vapor spark source.
- Develop reliable calibrated beam current detectors.
- Develop rugged transparent scintillators (e.g. sapphire, Eu-doped calcium fluoride coating).
- Improve emittance measurements with slits, scintillator and Optical Multichannel Analyzer (OMA). Investigate linearity of beam current vs. light output.
- Emittance control (increase) by grids.
- Change gun perveance and look for increased beam current. Transport of a higher current through the drift-tubes would require at least partial neutralization.
- Develop an electron beam probe for beam profile measurement.
- Examine practical schemes for using multiple beams in an induction linac, including matching.

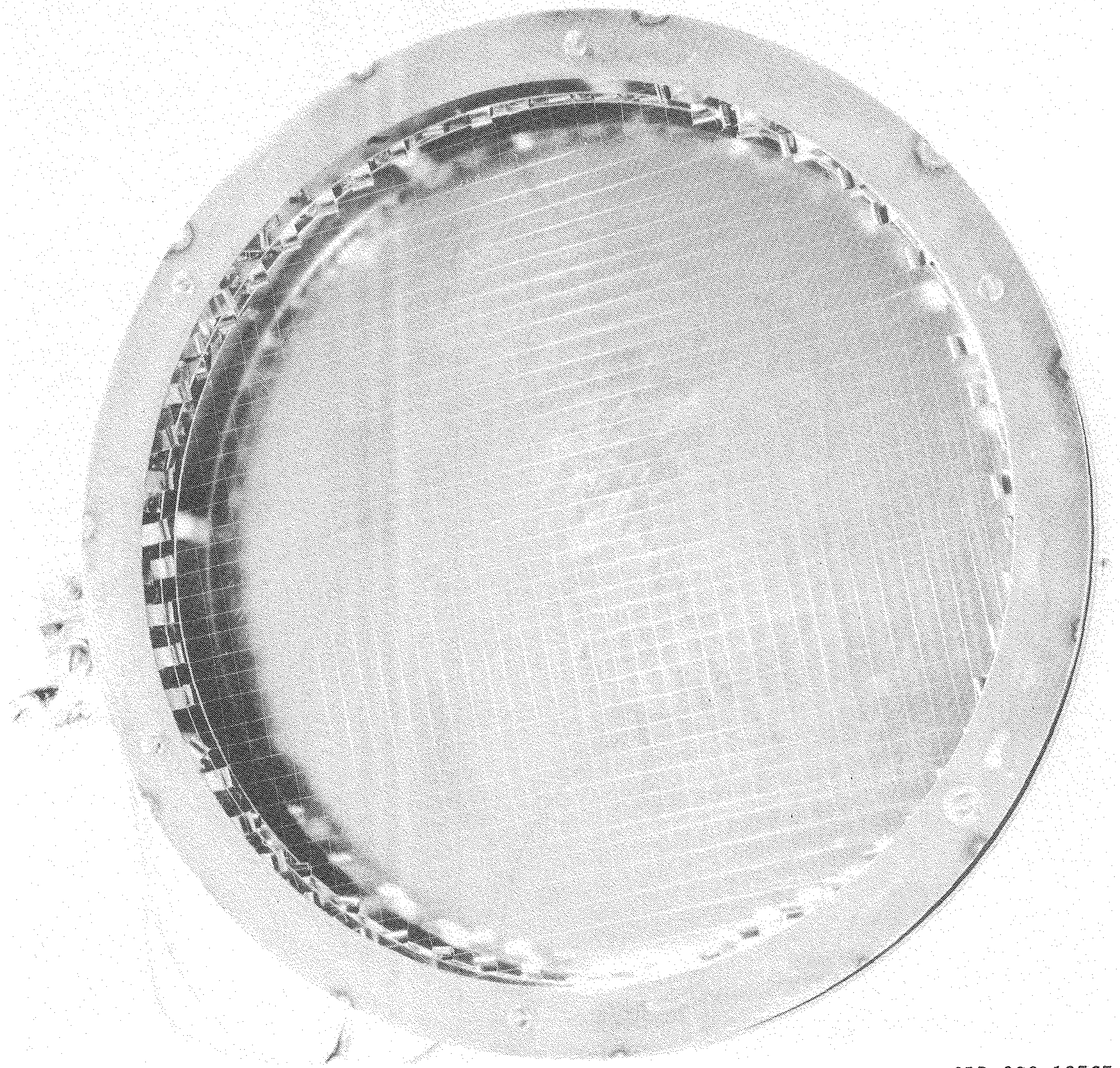
3. Diagnostics Development

We have invested a major share of our effort in developing reliable means of characterizing these intense, low energy ion beams. The problem of measuring total beam current has been more difficult than expected because of the high surface heating due to the short range of the ions. This leads to the evolution of an energetic plasma from the charge collector and nearby surfaces which requires a deep cup with suitable biasing to obtain reliable current measurements. We have finally arrived at an acceptable design which gives the expected saturation behavior with bias of its two grids and collector. This cup, shown in Fig. 2, has been used for all recent total current measurements.

The beam envelope has also been measured by means of a small scanning charge collector. This collector can be moved independently in r, θ, and z with a precision of ±0.06 mm, ±0.1 degrees and ± 0.8 mm respectively. A typical scan of the beam profile in the diagnostic tank is shown in Fig. 3.

In addition, we have measured the beam emittance in each transverse phase plane using a plate with fine slits to reduce the spreading effect of space charge. The beam divergence was measured both by a small flag probe and by a fast scintillator and camera, in order to achieve time resolution within the particle bunch.

Fig. 4 shows the arrangement of these elements in the diagnostic tank. The scintillator used recently has been a 1 μm thick layer of CaF_2 doped with europium, vacuum-evaporated onto a stainless steel plate. The scintillator is required to have a fast fluorescence decay time (~ 300 ns or faster), good efficiency of light production; and a usable lifetime in the intense beam (~1mA/cm^2). For example, Pilot B survives only 50 pulses under these conditions. KBr, which has been used previously has a slower fluorescence decay time and a lower light yield than the CaF_2 (Eu). The CaF_2 (Eu) scintillator was viewed with an EG & G Optical Multichannel Analyzer (OMA) with a lens mounted on it. This system functions as a gateable (gate width as narrow as 40 ns), high sensitivity television camera. A typical light intensity pattern for 1 mm slits 15 mm apart, 62 cm from the scintillator obtained with this device is shown in Fig. 5. The scintillator can be replaced by the movable charge collector and the pattern acquired more



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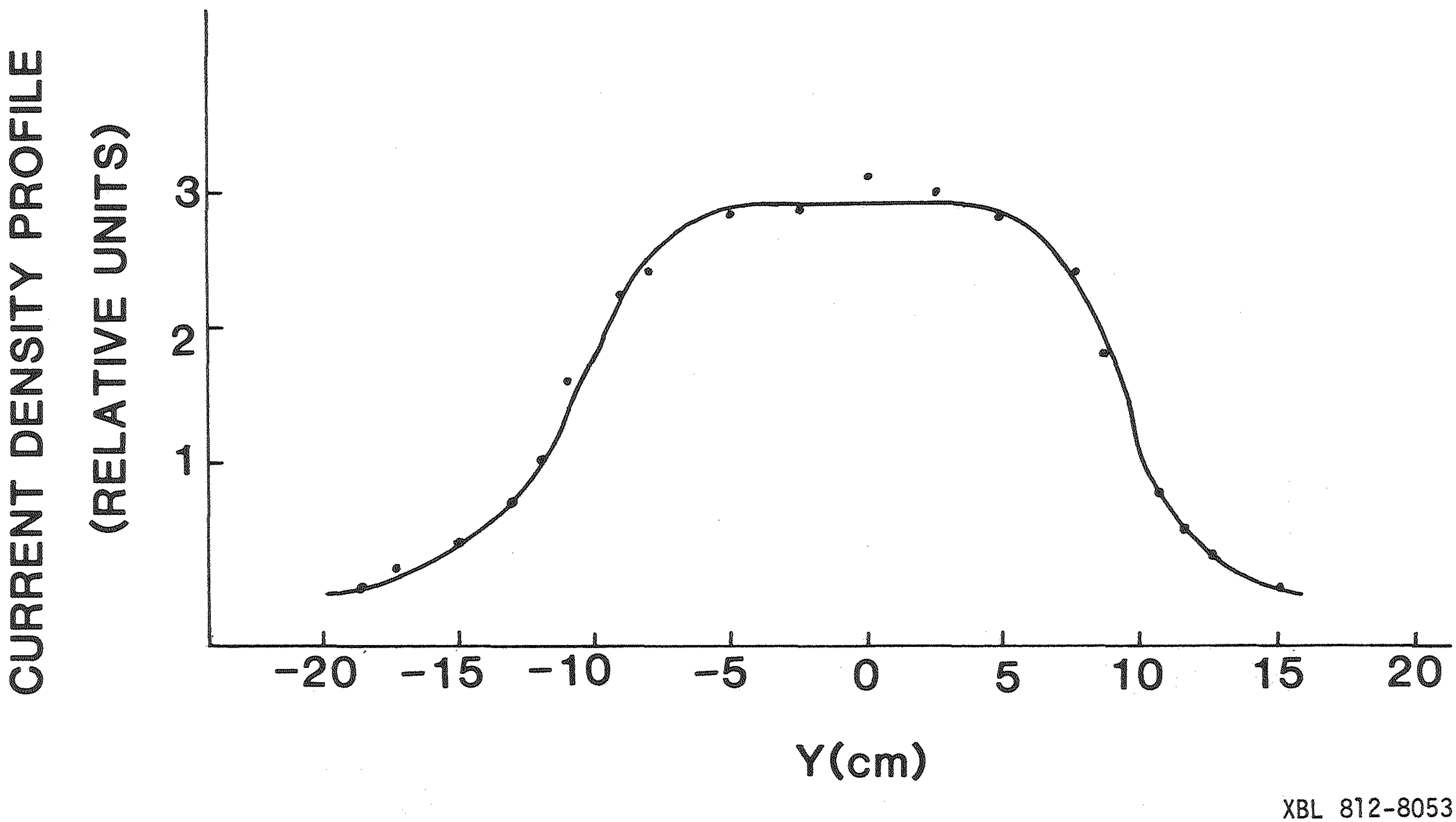
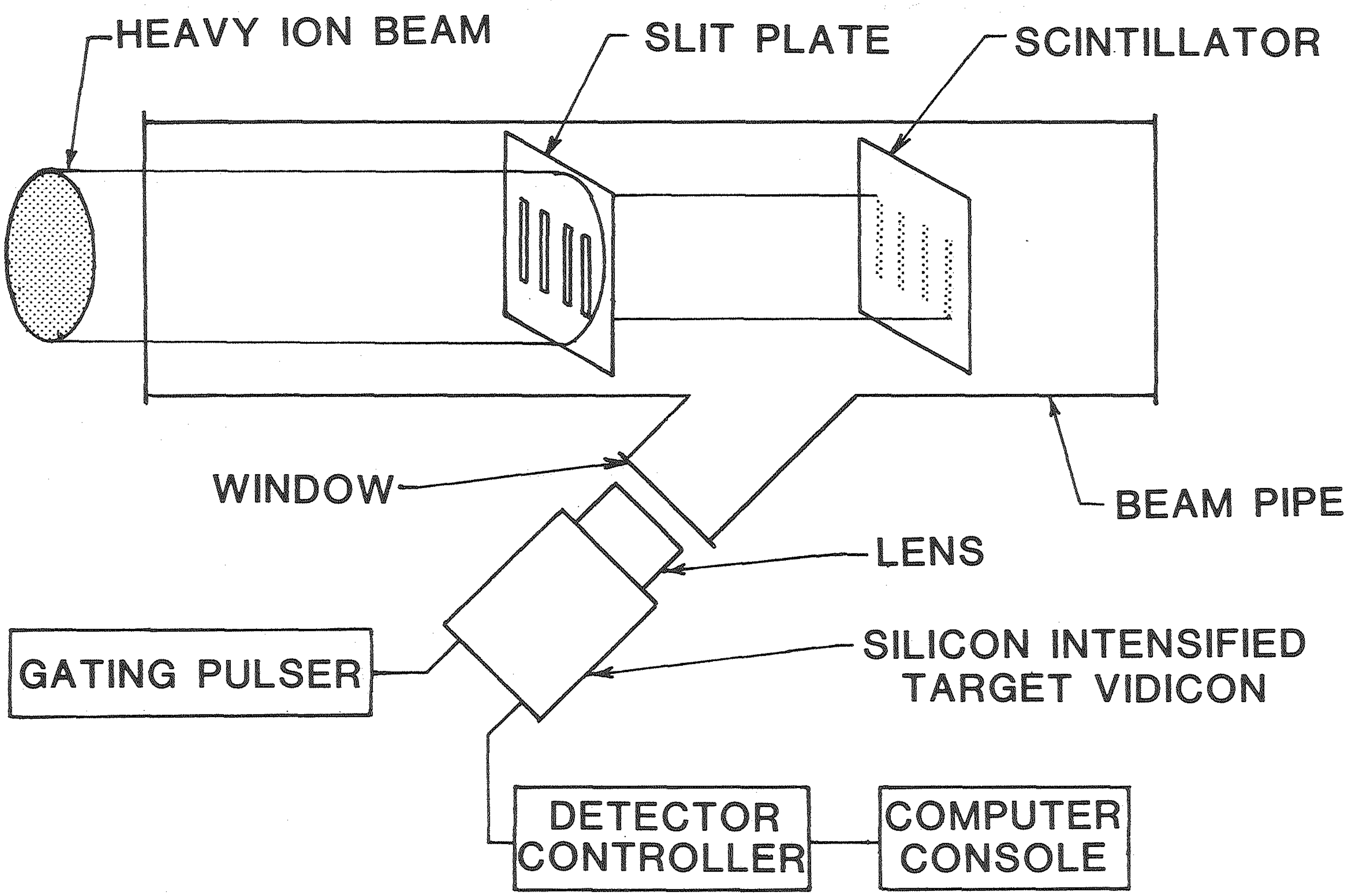
BIASED FARADAY CUP

Figure 2



BEAM PROFILE IN DIAGNOSTIC TANK

Figure 3



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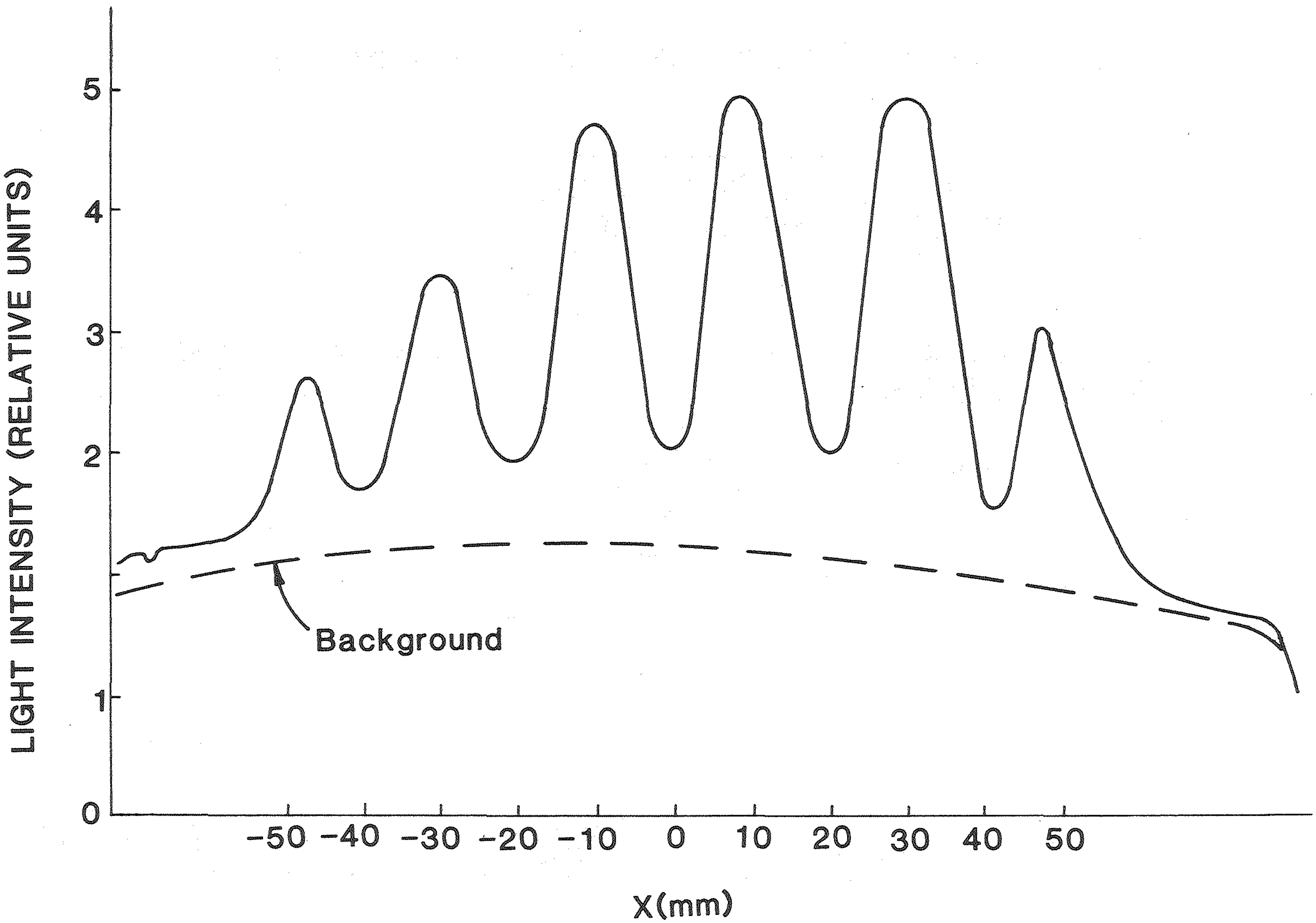
EMITTANCE MEASUREMENT SCHEMATIC ARRANGEMENT

Figure 4



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SCINTILLATOR LIGHT INTENSITY PATTERN OBSERVED BEHIND SLITS

Figure 5

laboriously, point by point; an example of such data is shown in Fig. 6. It should also be pointed out that these measurements required a high level of machine stability and reproducibility over $\sim 10^3$ pulses.

Note that Fig. 5 represents a beam scan in the X-direction and Fig. 6 is a scan in the Y-direction, and thus results for both transverse phase planes are shown. The emittance $\pi \epsilon_N \sim 2 \times 10^{-6} \pi$ m-radians is the same in both directions and is of higher quality than required for a heavy ion injector for an HIF Induction Linac for ICF purposes.

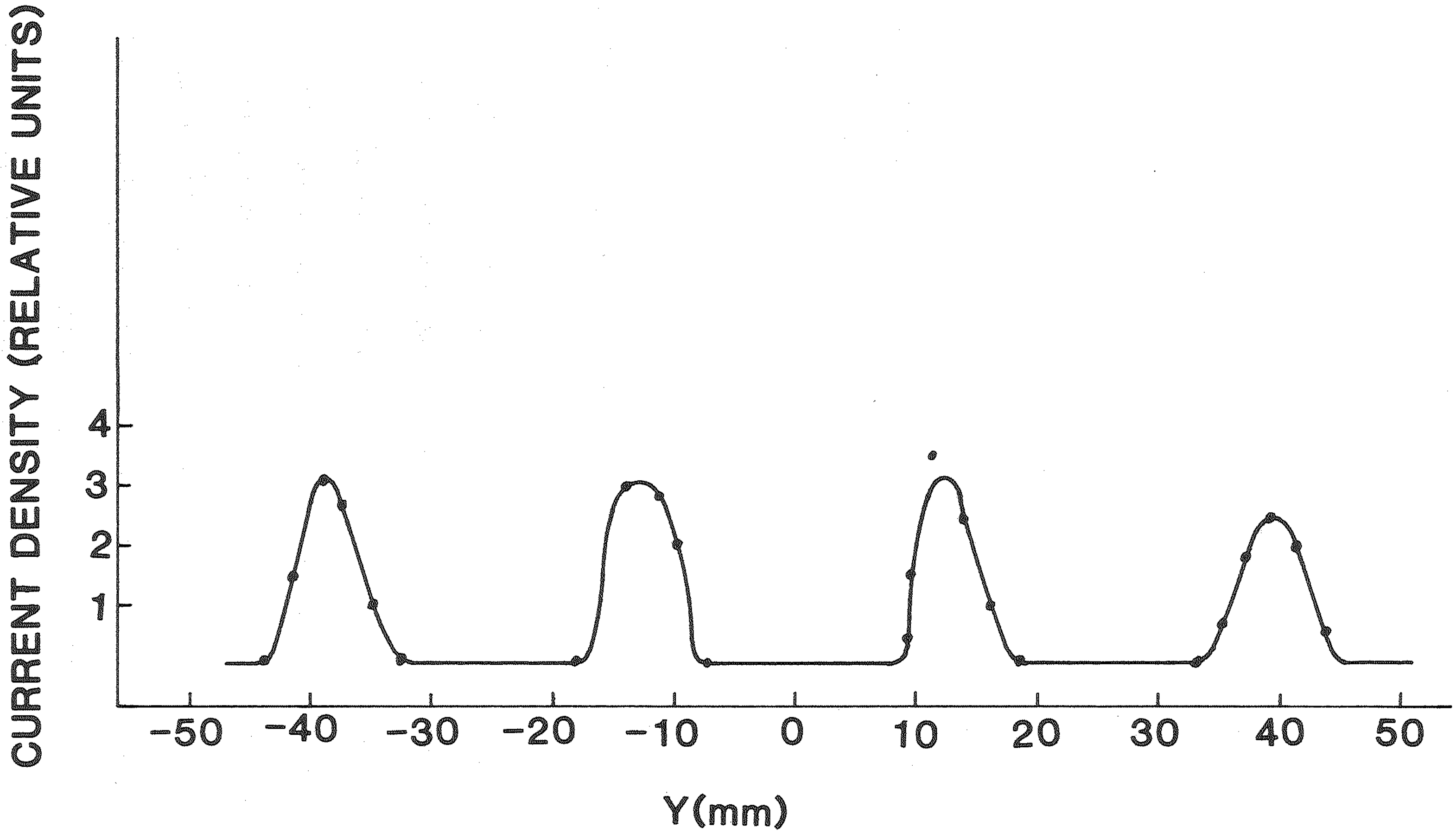
We have added a 16" gate valve between the injector and the diagnostic tank. This permits changes inside the diagnostic tank that require opening the tank to air to be made rapidly (~ 1 hour turnaround time), e.g., this has allowed use of such techniques as a cellulose nitrate film to image the ion beam. This film must be removed after each pulse and then etched for examination.

4. Scintillator Development

During this period further work has been carried out on scintillators for heavy ion beam imaging.

Undoped CaF_2 has been compared to the original CaF_2 doped with Eu. The scintillation efficiency and flourescence lifetime were found to be the same. A more careful measurement of the exponential decay time of the scintillator has been made by creating a sharp break in the current pulse by crowbarring DT3 early. This gave a value $\tau = 300$ ns. In addition we have measured the destruction rate of the scintillator in our intense ion beam. At a current density of 0.8 mA/cm^2 the light output decays exponentially with the number of pulses with a decay constant of 900 pulses.

A transparent scintillator has also been fabricated by coating 1 μm of



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MEASURED CURRENT PROFILE BEHIND SLITS

Figure 6

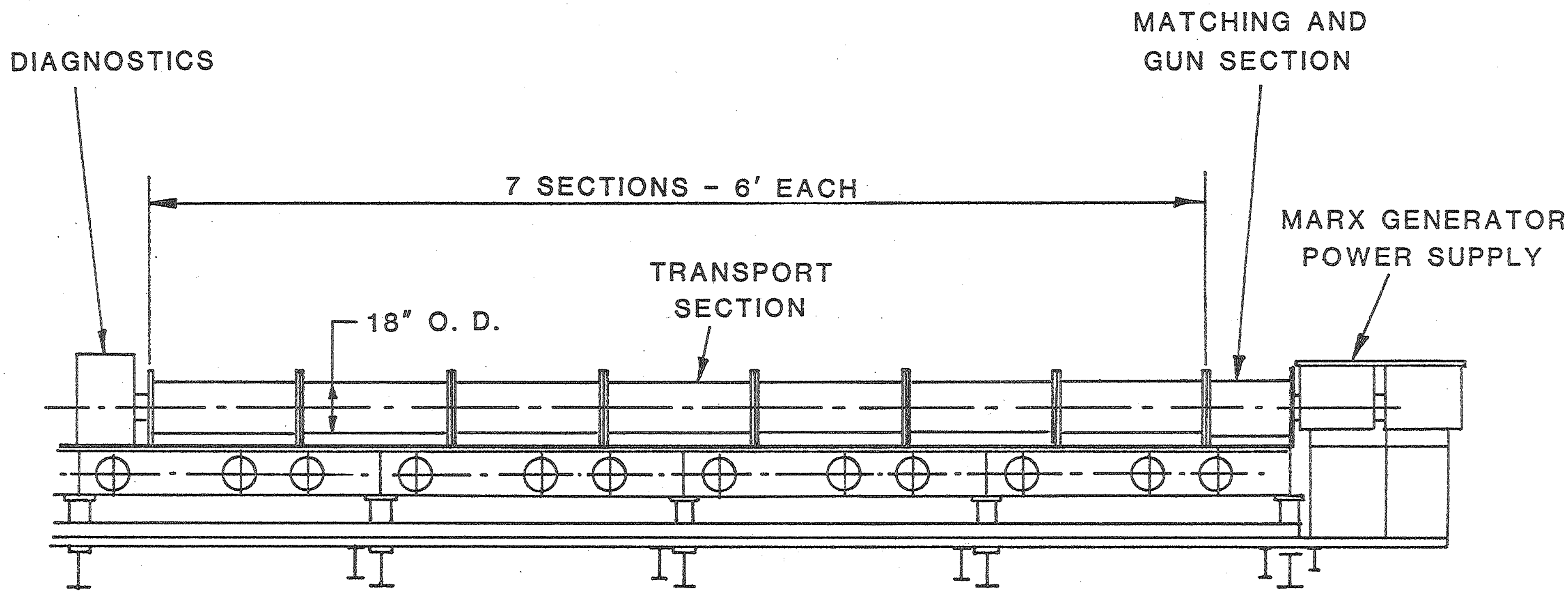
CaF_2(Eu) onto a commercially available conductive glass (Optical and Conductive Coatings Inc., Pacheco, Ca., sheet resistance = 3.9 ohms/square, 86% transparent in visible region). This scintillator was viewed in transmission and worked quite well.

In addition several other materials were tested as scintillators; 99.5% sintered Al_2O_3, 85% sintered Al_2O_3, single crystal Al_2O_3 (sapphire), BaF_2 crystal, LiF crystal, CaF_2 crystal. The best of these was the 99.5% sintered Al_2O_3 which had a larger light output than the CaF_2(Eu) and a shorter scintillation decay time. However, the sapphire crystal has no visible light output. We are planning to measure the impurities in these materials to find out which ones are responsible. A doped sapphire might make an excellent transparent scintillator although the CaF_2(Eu) on conductive glass works quite well for the present.

B. SINGLE BEAM TRANSPORT EXPERIMENT

A versatile apparatus has been designed and the fabrication begun for the single beam transport experiment during the present reporting period. The objective of the experiment is to study the transverse beam dynamics and the stability of a space charge dominated heavy ion beam traveling through a long periodic focussing channel under a wide variety of beam parameters.

The machine comprises three major parts; the long transport channel, the ion injector, and the matching section as shown in Fig. 7. The transport channel has 82 electrostatic quadrupole lenses, each of which is 4" long and separated from the adjoining ones by 2". The gaps are for insertion of various beam diagnostics. The clear bore of the quadrupole is two inches in diameter. The shape of the quadrupole electrodes is designed in such a way that the nonlinear components of the focussing field due to the ends of the electrodes are minimized under the given constraints.



HIF - SINGLE BEAM TRANSPORT EXPERIMENT

Figure 7

The kinetic energy of the beam can be varied up to 200 keV. The range of beam parameters for various tunes for a 200 keV Cs^+ beam are summarized in Table 1 below.

$\sigma_0 = 120^0$	$V_Q = 21.0$ kV $\sigma = 6^0 \sim 100^0$ $I = 50$ mA ~ 7 mA $A \approx 1.5$ cm
$\sigma_0 = 90^0$	$V_Q = 17.1$ kV $\sigma = 4^0 \sim 80^0$ $I = 32$ mA ~ 7 mA $A \approx 1.5$ cm
$\sigma_0 = 60^0$	$V_Q = 12.1$ kV $\sigma = 3^0 \sim 50^0$ $I = 20$ mA ~ 7 mA $A \approx 1.5$ cm

Table I. Beam Parameters for various tunes for 200 keV Cs^+ beam.

The injector was designed with the EGUN code and is capable of providing low-aberration ion beams with the necessary beam parameters shown in Table I. It is composed of a Zeolite ion source, a Pierce electrode, four extraction electrodes, and emittance control grids, as shown in Fig. 8. Although we are primarily interested in Cs^+ ions the Zeolite ion source can produce any alkaline-earth metal ion. The beam current can be varied from 20 mA to 60 mA for a 200 keV Cs^+ beam. The emittance of the beam can be varied from the thermal value of $8 \times 10^{-8} \pi m \cdot rad$ to some 6×10^{-7} $\pi m \cdot rad$ by means of the emittance control grids. They are composed of three parallel grids located in a relatively field-free region in between the injector and the matching section (Fig. 8). The emittance control is necessary to generate a matched ion beam with a convenient size and a current which is easier to diagnose.

SINGLE BEAM TRANSPORT EXPERIMENT

ION INJECTOR

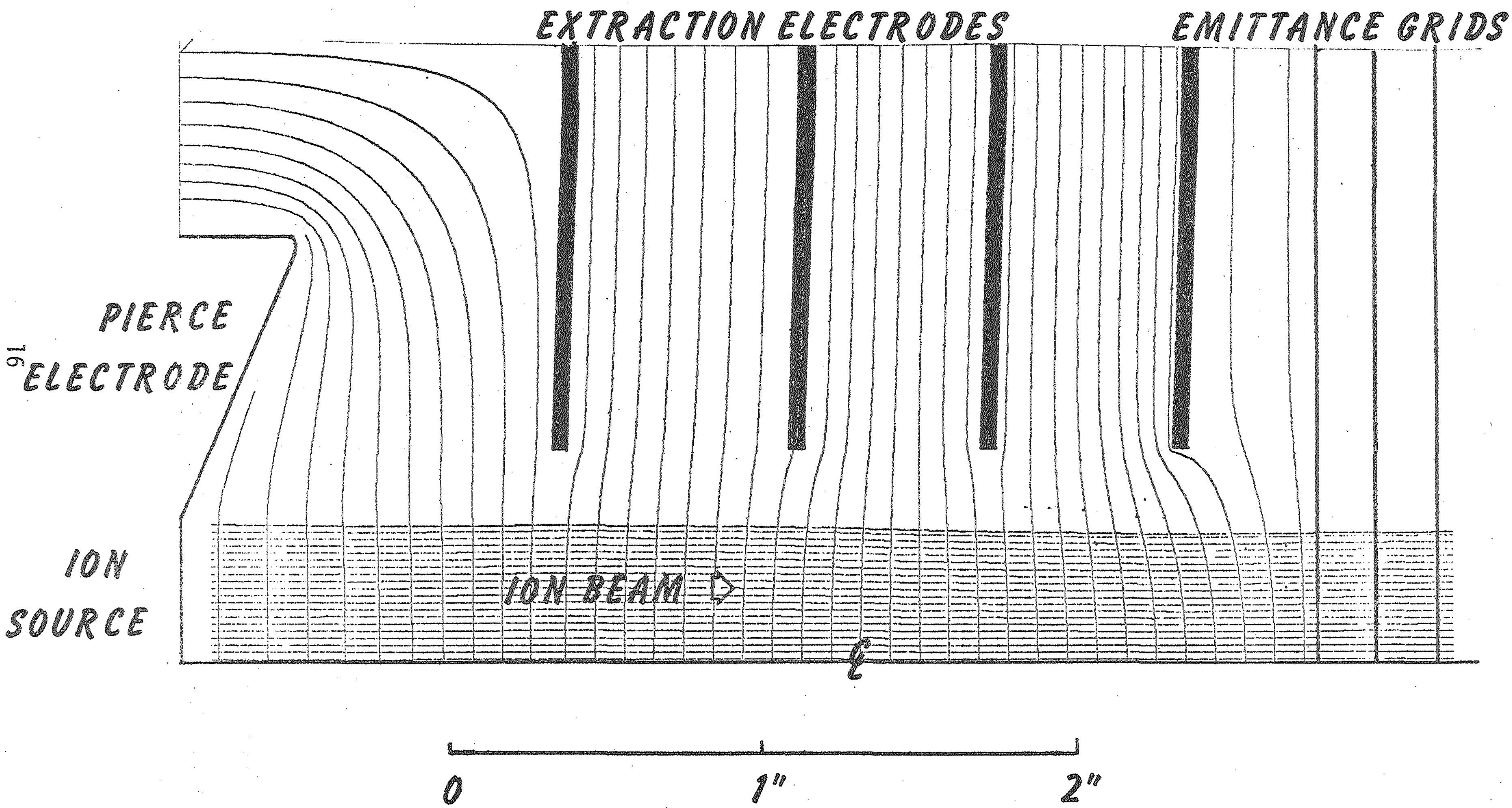


Figure 8

The matching section is composed of five quadrupole lenses as shown in Fig. 9. The voltage on these lenses can be individually adjusted to transform the beam cross section gently from the round one to the elliptical one of the right shape for the transport channel. The SYNCH code is being used for the matching calculation and for establishing the beam tuning procedure.

Orders have been placed for the quadrupole electrodes, the electrode supporting structures and the vacuum tank. Delivery is expected in mid-May. The injector is being designed and will be fabricated in-house.

C. MULTIPLE-BEAMLET HEAVY ION INDUCTION LINAC

1. General Considerations

The program for developing an induction linac driver for heavy ion fusion has been redirected to incorporate the concept of multiple electrostatically focussed beamlets as proposed by Al Maschke (BNL) for the rf low-beta accelerator. Individual beamlets using electrostatic quadrupoles are formed with their physical pulse lengths (a few meters), equal to, or only slightly longer than, the physical pulse length desired at the target. Pulse compression is achieved by simply restraining the pulse length from growing as the beam is accelerated. Thus, for example, if the beam kinetic energy is increased by a factor of 100, the velocity and hence, the current, are increased by a factor of ten. The transverse focussing system, consisting of small-aperture electrostatic quadrupoles with relatively modest voltages (a few kilovolts), is unchanged by the acceleration process with only one significant exception; the periodic length is increased proportional to beam velocity. Transverse dimensions, beam profile, focussing fields, are all unchanged so long as the linear charge density is unchanged.

The acceleration process occurs in short gaps, defined by metal plates with an individual hole for each beamlet as shown in Fig. 10. The effects of

SINGLE BEAM TRANSPORT EXPERIMENT
CALCULATED BEAM ENVELOPE

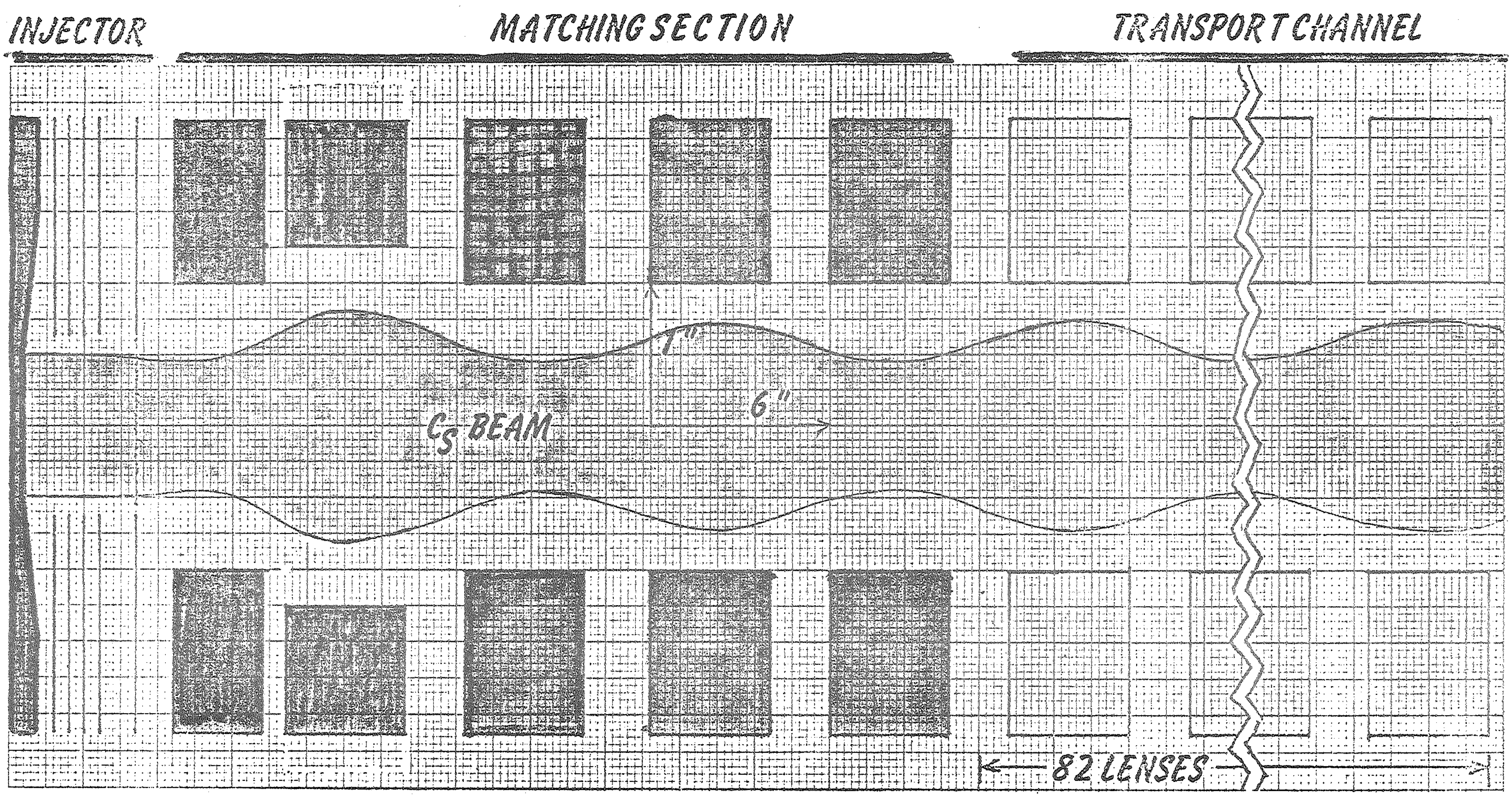
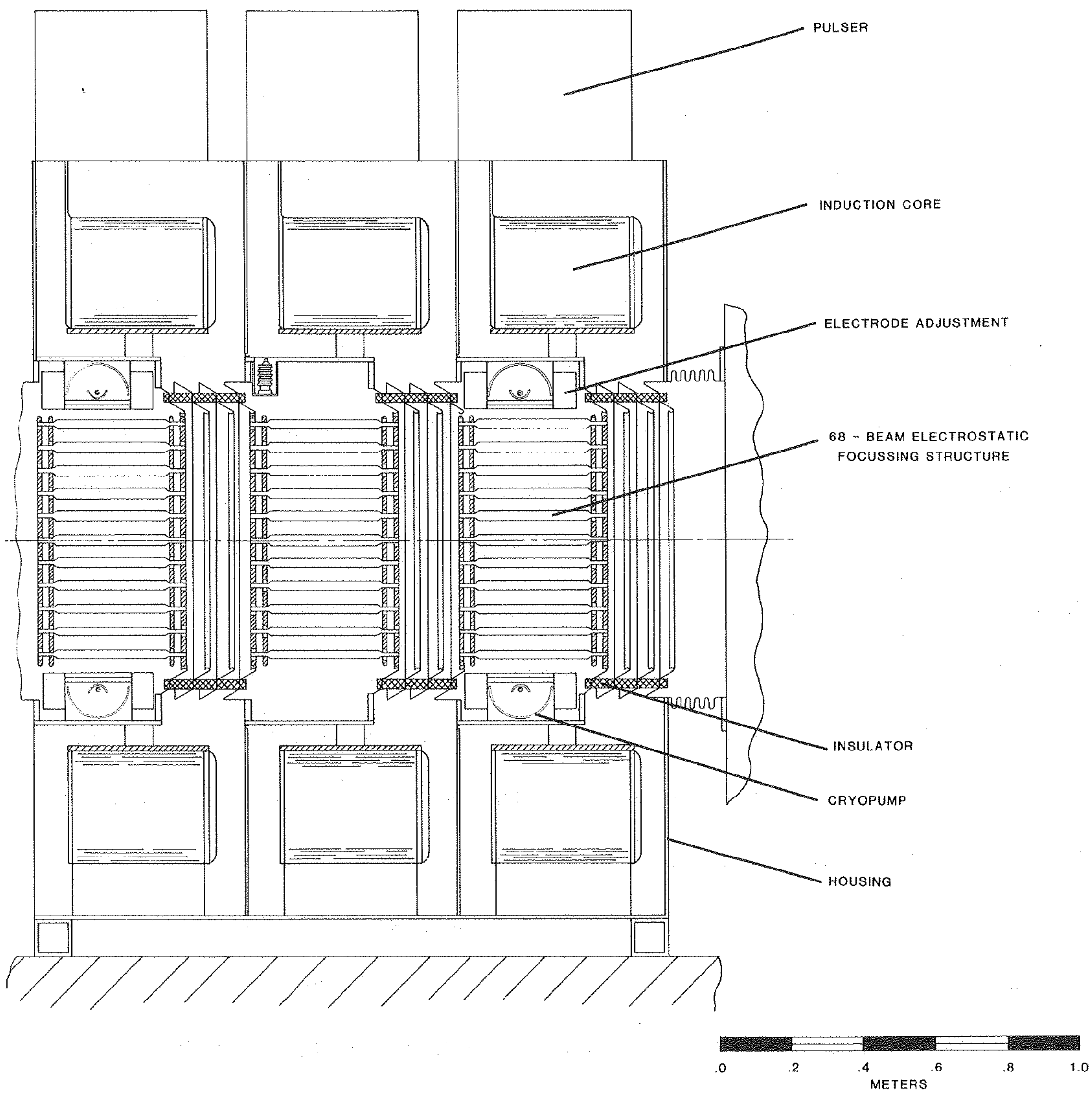


FIGURE 9



MULTIPLE BEAM INDUCTION LINAC - SIDE SECTIONAL VIEW

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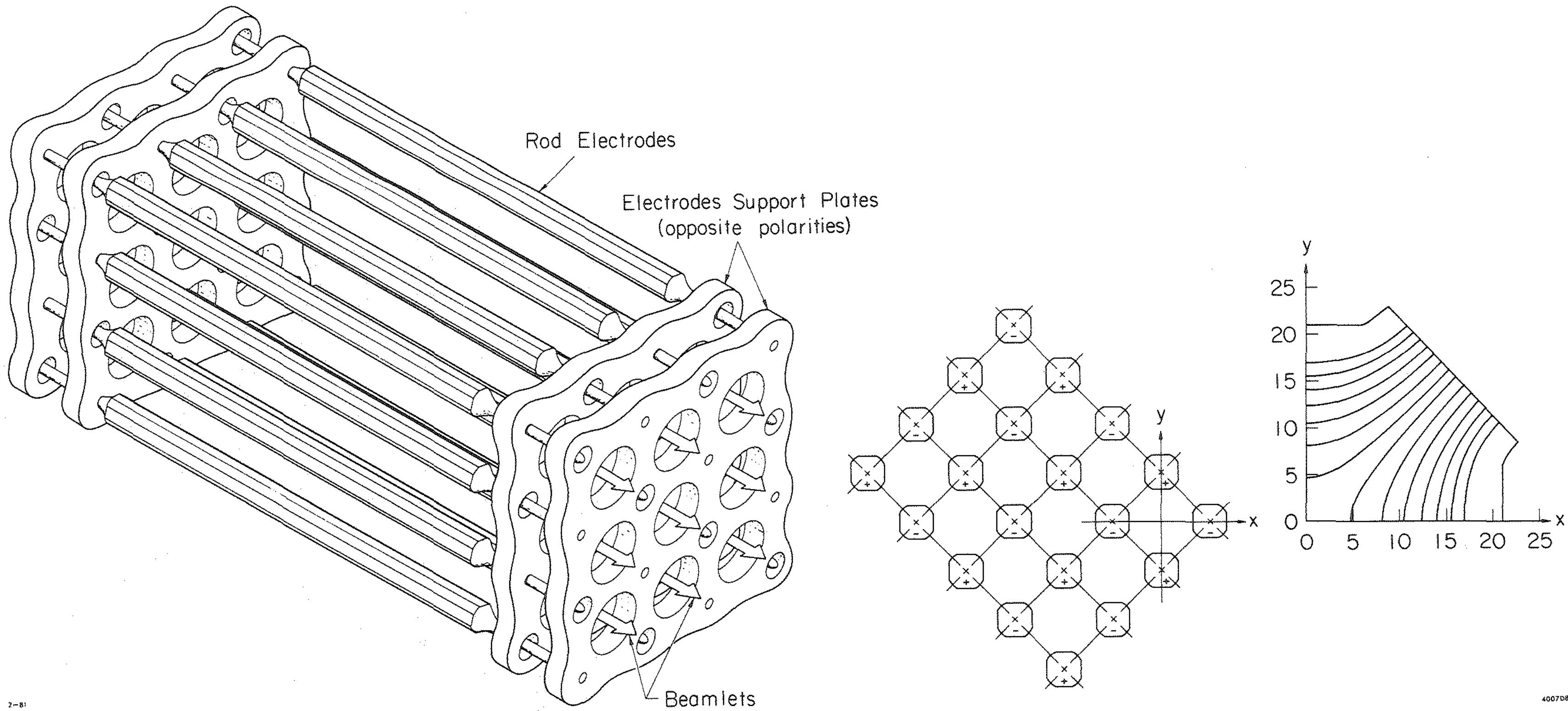
Figure 10

adjacent beamlets on each other are shielded except in the acceleration gap where they are canceled, to the first order, by the presence of beamlets on all sides. Moderately-large-aperture induction modules are envisioned, up to about one meter diameter, spaced as close as their requirements for linear space allow. Electrostatic quadrupole arrays and pumping systems are interspersed between accelerating modules.

The advantage of the multiple beamlet electrostatic quadrupole transport system is that the current that can be transported is a better match to the performance of the induction linac. This is especially true at low energies, where the velocity of the ions is so low that long, low-current pulses would require uneconomically long pulse lengths. Although it is possible ultimately to combine beamlets into larger bunches, there is no obvious reason why the individual beamlets could not be transported from ion source to target pellet.

An artist's conception of a section of multiple beamlet quadrupole structure is shown in Fig. 11a. In Fig. 11b, the cross section of the ends of the rods are drawn showing the flattened sides facing the beamlets. A computer plot of the equipotential lines in a single quadrant is shown in Fig. 11c. This configuration results in focussing fields that are linear to within ± 1% over more than 95% of the aperture.

If the current transported increases only with velocity, i.e., there is no bunching other than the pulse shaping needed to maintain constant bunch length, then the transverse focussing strength needed is independent of velocity. The length of a quadrupole period, however, must increase proportional to velocity. Thus, a number of quadrupole structures, such as that in Fig. 1, are at the same polarity until a length corresponding to half a period has been achieved, at which point a similar number of quadrupoles is set to the opposite polarity. In this way the electrostatic quadrupole can



11a 11b 11c

MULTIPLE BEAMLET QUADRUPOLE ARRAY

Figure 11

compensate for the relatively weaker focussing strength, compared to magnetic focussing, at higher velocities.

Constant bunch length requires that the average velocity of the head and tail of the bunch be the same: thus, the energy of the tail of the bunch has a higher energy $\delta E = \ell dV/dz$ (where ℓ is the length of the bunch and dV/dz is the average accelerating gradient.) This energy increment needs to be imposed only once, at injection, and must be adjusted only if the accelerating gradient changes.

The space charge depression in the middle of a long beam acts to try to push the beam apart at the ends. The beams proposed here are a few meters long. It is planned to put small "ears" on the accelerating waveforms to confine the beams longitudinally. The ear at the leading edge is just a slightly delayed pulse, not accelerating the front of the pulse, and is essentially free. The ear at the trailing edge must "push" by an average field as great as the space charge depression divided by the (assumed) linear ramp length of the tail of the beam. The space charge depression is given by $30\ I/\beta$, which is a constant in this concept amounting to a few hundred volts. If the tails of the bunches are a few centimeters long, the ears are a few kilovolts per meter.

It is on this point of longitudinal confinement that another advantage of the multiple beamlets becomes evident; if all the charges are in one large "sausage" as in earlier concepts, the longitudinal ears are much larger. The problem then becomes a three-dimensional one of confining a short, fat sausage of charge rather than the long, thin "conventional" bunch suggested here.

The final focus system and the transport of the beam to the target appears to be surprisingly easy with the many small beamlets. Since the individual beamlets can be separately aimed at the pellet, the problems of large aperture chromatic and third order aberrations are all essentially eliminated. The space charge limited current that can be directed to a target (typically 2.5 mm radius at a distance of 10 m from the final lenses) is about 40 A from a beamlet with initial radius of about 1.0 cm. This assumes 10 GeV heavy ions with atomic mass above 200. This is comfortably above the needed current per beamlet and, further, a large cluster of beamlets, an array of perhaps 1 meter diameter, could also be focussed to such a spot with nearly two times the total current that is required.

The next step, which is in a preliminary planning phase, is to build a small version of the full-sized driver. It could be perhaps a 100 MeV model carrying about 10% of the charge needed for a full-sized machine but including all the essential components. It is interesting to note that ions of any charge or mass can be accelerated with this system; thus for middle weight ions, such as sodium, higher beam power can be achieved with a low-energy accelerator. The ions would still have adequately short range and, as has been shown by Jim Mark of LLNL, interesting temperatures in excess of 100 eV can be achieved by focussing the beam on a sufficiently small spot. Electron neutralization of the final beam can be used to avoid space charge spreading.

2. Multibeam Induction Linac Cost Studies

System studies work continued on accelerator sections of Drivers with emphasis on multiple beams in the accelerator.

The multibeam magnetic focussing element model used in the Linear Induction Accelerator Cost Evaluating Program (LIACEP) was improved so as to allow better packing of beams (HI-FAN-151). Some of the cost algorithms were changed to reflect more realistically the accelerator configuration. Typical trends in accelerator costs, with these modifications, are shown in Fig. 12, relative accelerator cost for a 3 MJ Driver, Tl^+ for this case, as a function of total beam charge. One sees that multibeam accelerators are 30%

3 MJ, Tl^{+1} DRIVER – ACCELERATOR COSTS

$\Delta \nu = 60° - 24°$

rep rate= 1 Hz

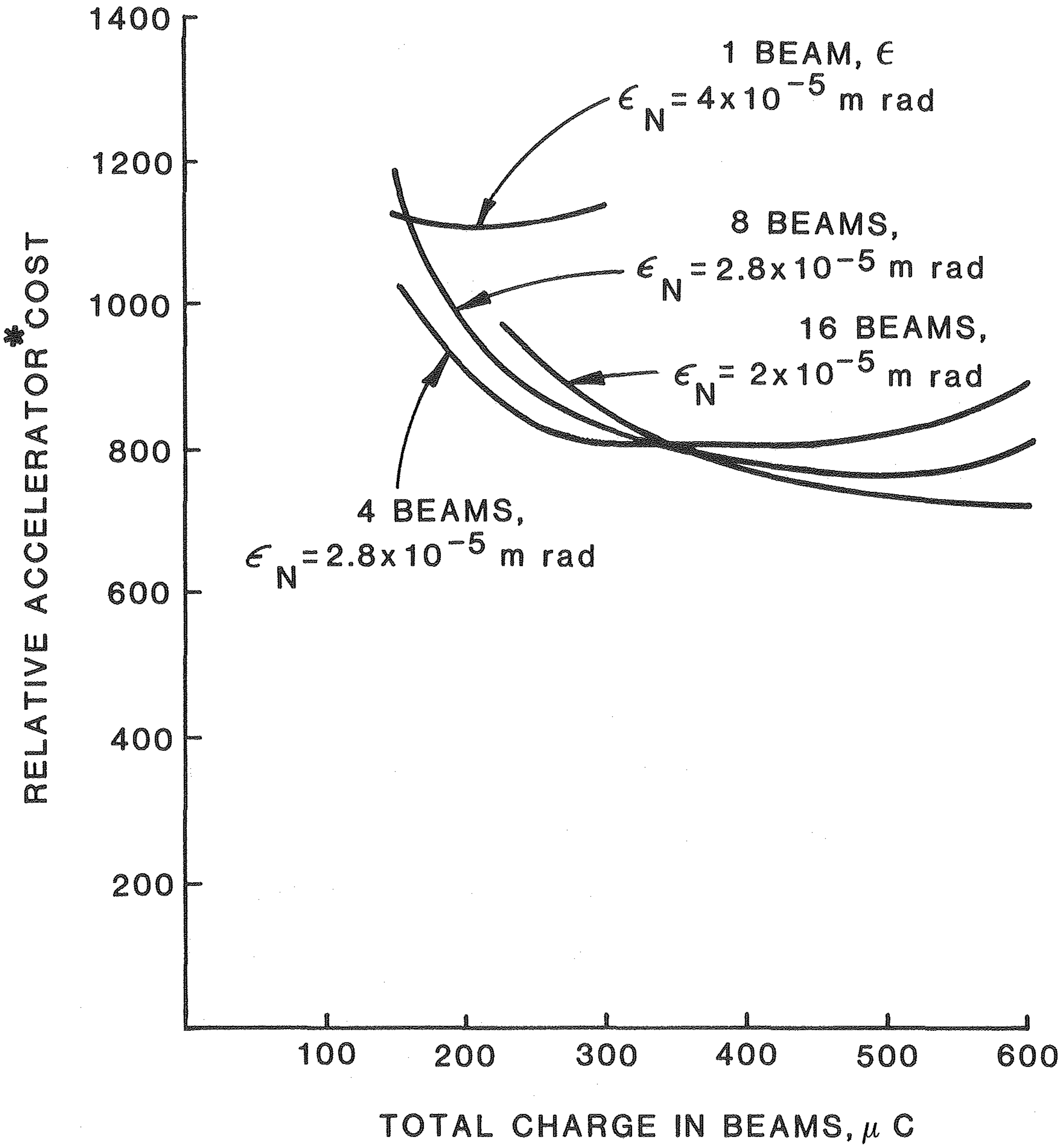


Figure 12

*ACCELERATOR ENERGY, 50 MeV TO FINAL PARTICLE ENERGY less costly than an accelerator with just 1 beam. Interestinaly, from the parameters chosen, the cost of either a 4, 8 or 16 beamlet accelerator is essentially the same in the 300-450 μC range. The fact that the 4, 8 or 16 beamlet accelerators are nearly equal in cost could provide some flexibility in the accelerator design when matching the injector and final beam transport to the accelerator.

Generally, higher efficiencies come with higher total beam charge and more beamlets in the accelerator. Figure 13 shows how efficiency is increased with repetititon rate from 1 to 10 Hz. Figure 14 gives accelerator length as a function of total beam charge and the number of beamlets in the accelerator for the Tl^+, 3 MJ Driver. Accelerator length decreases with an increase in beam charge and the number of accelerator beamlets.

The ability to examine multiple beams with electrostatic focussing has now been incorporated into the LIACEP program. In the induction accelerator model 16 to 512 beamlets can be considered. Preliminary results are being obtained.

D. THEORY

1. Longitudinal Simulations

The longitudinal simulation code developed by Haber has been used to study various effects associated with the propagation of density and velocity disturbances on continuous and bunched cold beams, in preparation for dealing with specific cases of practical interest. For a continuous cold beam, the dynamics are also described by a non-linear partial differential equation similar to the well-studied Korteweg-de Vries equation and the computer runs show qualitatively similar effects. For example, a density perturbation of length L and amplitude A ($A = \alpha$ times unperturbed density) sharpens and steepens after traveling a distance, L/α, along the beam. If the dispersion due to the influence of pipe radius at short wave lengths is included, such a

3 MJ, TI $^{+1}$ DRIVER
ACCELERATOR EFFICIENCY FOR 1–10 Hz
WITH 8 BEAMS

$\Delta \nu = 60^\circ - 24^\circ$

$\epsilon_N = 2.8 \times 10^{-5}$ m rad

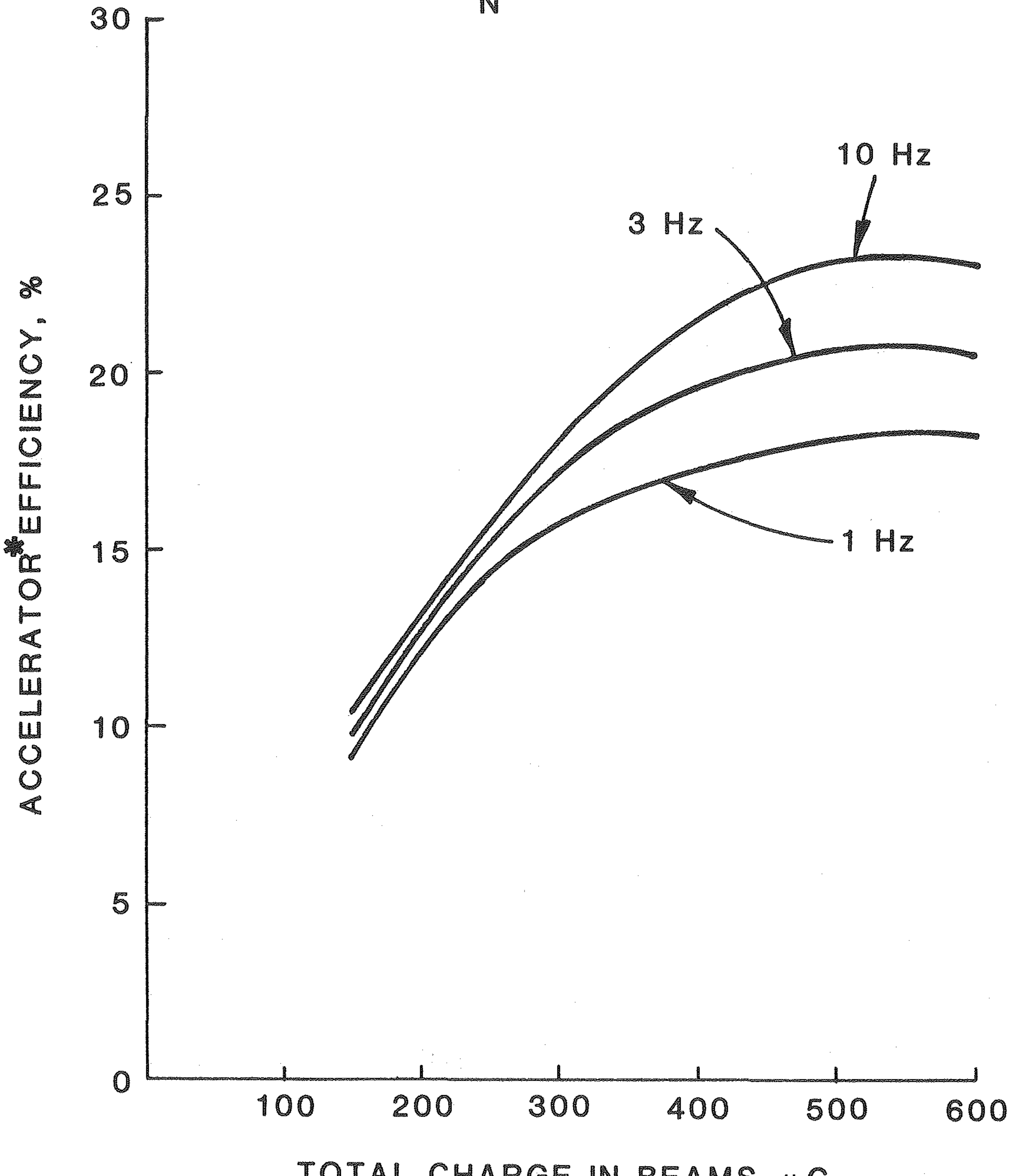


Figure 13

*ACCELERATOR ENERGY, 50 MeV TO FINAL PARTICLE ENERGY

3 MJ, Tl^{+1} DRIVER – ACCELERATOR LENGTH

$\Delta\upsilon = 60° - 24°$

rep rate = 1 Hz

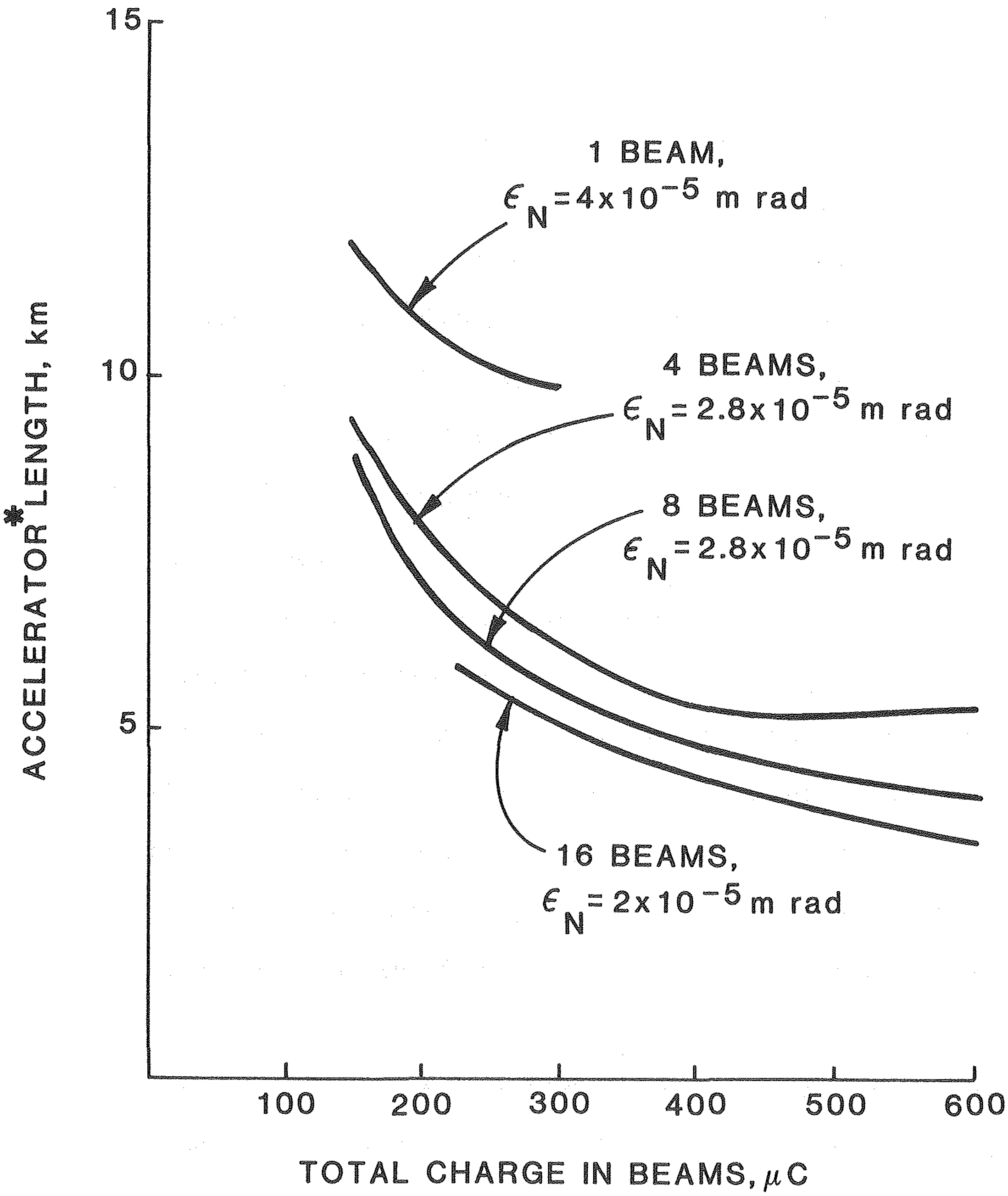


Figure 14

* ACCELERATOR ENERGY, 50 MeV TO FINAL PARTICLE ENERGY

perturbation breaks into a train of bumps, suggesting the creation of solitons. This effect is enhanced by a linear growth due to a resistive wall impedance. Linear growth rates agree with linearized Vlasov theory, as do threshold values when a velocity spread is introduced, which facts indicate that the code is working properly.

2. Longitudinal-Transverse Coupling

Progress has been made toward the solution of the longitudinal-transverse coupling problem described in previous reports. For the model of a continuous beam with transverse K-V distribution and uniform axial velocity, an expression for the frequencies of the possible modes of the system has been derived in the form of an infinite determinant. The frequencies are found by truncating the determinant and then checking that the values are not significantly altered if the rank of the determinant is increased. At low intensities, the well-known longitudinal and transverse modes are easily identified; however, there also appear two new sets of modes peculiar to the coupled motion. At high intensities, the frequencies of the various mode are comparable and, where they meet, new instabilities appear. The most notable of these is an interaction between a transverse mode and the new modes, with a threshold at $\nu/\nu_0 \sim 0.3$. The wall impedance strongly affects the familiar longitudinal mode and, to some extent, the transverse envelope oscillation mode, but has little effect on other modes, which involve rearrangements in the interior of the beam.

We are currently investigating the effect of a longitudinal velocity spread in the expectation that it will damp the instabilities. The model can also be easily extended to include the presence of neutralizing electrons which are free to move in the axial direction. We expect that the electrons well tend to suppress the usual instabilities, but will undoubtedly give rise to two-stream instabilities unless the electrons travel with the beam.

3. Electrostatic Quadrupole Transport

In connection with the single beam experiment and in anticipation of multiple beam designs, analytic and numerical relaxation techniques have been used to determine electrode changes which minimize non-linear components of the field, subject to the constraint of simple fabrication methods. In the presence of non-linear forces and aberrations due to changes in kinetic energy of the ions in an electrostatic field, it is not known what constitutes a matched beam, if indeed there is such a thing.

Using the parameters of the single beam experiment, a self-inconsistent match has been established by integrating the envelope equation, using the non-linear external fields at the beam edge. Individual orbits are then integrated in the resulting external plus space charge fields. The aberrations are not significant unless the parameters correspond to an extreme tune depression in the linear approximation, for example, from 60^{0} to 10^{0} per cell. Then some individual orbits appear to be unstable. When parameters of the matching lenses of the experiment are firmly extablished, the EGUN code will be use to find self-consistent solutions.

4. Storage Rings

LBL was asked to devote some of its theoretical effort to problems connected with the R.F. linac-storage ring approach to HIF. It was decided to concentrate first on storage rings, since the performance of a linear accelerator is much better understood than such matters as beam stability and manipulation in a storage ring for the required parameter range. The principal result of this work to date has been an analysis of the feasibility of an experimental investigation of significant phenomena on existing machines. Eight machines were considered as likely candidates, including the proposed Argonne ADF. The conclusion is that, apart from the ADF, the Rutherford SNS, still under construction, is the only device that could provide a clean test; that is, experiments which would replicate the real situation in a relatively unambiguous way.

E. INDUCTION MODULE DEVELOPMENT

Development and testing of induction module components has continued at a low level. Discussion with representatives from English Electric Valve, Inc. and Varian/National, Inc. have led to various ideas about how to reduce the firing jitter and increase the lifetime of ignitrons in induction linac service, including a combination ignitron/spark gap, and a gridded ignitron. We plan to cooperate with the manufacturers in testing these ideas out.

An extremely interesting and promising gridded ignitron tube is in the process of being characterized. The tube is a one-off experimental device which was specially constructed for us by Varian/National, Inc. The tube uses a standard igniter to initiate a mercury discharge, and a keep-alive auxiliary anode to maintain the initial discharge. The actual switching or commutation of the high voltage is controlled by a grid approximately midway between the anode and cathode areas.

Standard mercury ignitrons have been evaluated during the past year for suitablity in 25 kV, 10 kA pulsers of the type required in the front end of an HIF driver and in the two previously proposed test beds. The available tubes have typically had a life of 10^5 shots and a firing time jitter of 100 ns. The best hypothesis is that the rate of rise of the current has been responsible for the short lives, while the jitter has been normal. The experimental gridded tube works in a parameter regime where a large volume plasma is first established in the cathode region, and then switched to the anode, thereby allowing the current to be distributed more uniformly over the anode. In the preliminary tests conducted thus far (at 5-10 kV volts, limited by the desire to preserve the new tube as long as possible) jitter values below 10 ns have been achieved with a 500 volt pulse applied to a -200 volt biased grid.

We have also been working with representatives of Allied Chemical Corp in developing their Metglas® alloys as materials for induction module cores. They have recently delivered two new toroids of their 2605 SC and 2605 CO made out of 1.1 mil thick ribbon. Preliminary measurements indicate that the turn-to-turn insulation has been greatly improved over the last pair of toroids. A complete pulse magnetization measurement will be done in the near future.

F. PUBLICATIONS AND REPORTS

Number	Author	Title	Date
HI-FAN-125 (LBL-11120)	A. Faltens, E. Hoyer, D. Keefe, L.J. Laslett, L. Smith, R.O. Bangerter, and W. Herrmannsfeldt	Multi-Megajoule Heavy Ion Induction Linacs (Presented at the 8th International Atomic Energy Agency Conference on Plasma Physics and Controlled Nuclear Fusion Research, Brussels, Belgium, July 1-10, 1980)	7/10/80
HI-FAN-126	J. Krafft, T. Wang	Space-Charge Limits in Beam Plasmas Revisited (Abstract submitted for the 22nd Annual Meeting Div. of Plasma Physics, Nov. 10-14, 1980)	10/12/80
HI-FAN-127	J. Bisognano and W.K. Mark	The Warm Beam Equilibria and Some General Stability Considerations (Abstract submitted for the 22nd Annual Meeting Div. of Plasma Physics, Nov. 10-14, 1980)	10/12/80

HI-FAN-128	J. Shiloh, W. Chupp, A. Faltens, E. Hartwig, W. Herrmannsfeldt, D. Keefe, C. Kim, R. Nemetz, and S. Rosenblum	Cs^{+1} Injector for an Induction Linac (Abstract submitted for the 22nd Annual Meeting Div. of Plasma Physics, Nov. 10-14, 1980)	10/12/80
HI-FAN-129	A.M. Sessler	Heavy Ion Inertial Fusion (Abstract for an Invited Paper for the 22nd Annual Meeting Division of Plasma Physics, Nov. 10-14, 1980)	10/12/80
HI-FAN-130	W.B. Herrmannsfeldt	Injector Studies with Multiple Electrostatic Quadrupoles	10/21/80
HI-FAN-131	V. Brady	Fields for Various Electrostatic Cell Configurations	10/22/80
HI-FAN-132	J. Bisognano, L.J. Laslett	Longitudinal Field of Charge Distribution in Perfectly Conducting Pipe	7/3/80
HI-FAN-133 (LBL-11146)	D. Keefe and A. Sessler	Heavy Ion Inertial Fusion (Presented at the XIth International Conf. on High Energy Accelerators, Geneva, Switzerland, July 7-11, 1980) Experientia Supplementum, 40, 201 (1980)	7/80
HI-FAN-134 (LBL-11825) (UC-20b)	G. Krafft	Heavy Ion Fusion Final Focus System	10/80
HI-FAN-135	L.J. Laslett	Concerning Tune Depressions Less Pronounced than 60 to 24 deg. (or 90-36 deg.)	11/14/80
HI-FAN-136 (LBL-11809)	HIF Staff	Heavy Ion Fusion Half-Year Report April 1, 1980 - Sept. 30, 1980	12/3/80
HI-FAN-137	L.J. Laslett, V.O. Brady	Design of Electrodes for the Single-Beam Ion-Beam Transport Experiment	3/11/81
HI-FAN-138	L.J. Laslett	The Effect of Images in a Circular on the Envelope Dimensions and Tune of a Periodic (symmetrical) Magnetic-quadrupole Focussing Channel	12/19/80
HI-FAN-139	A. Faltens, D. Keefe, and S. Rosenblum	Ion Accelerators as Drivers for Inertial Confinement Fusion (Presented at the IEEE Conference, "The Application of Accelerators in Research and Industry", Denton, TX, November 3-5, 1980)	9/80

HI-FAN-140 (LBL-12204)	A. Faltens, E. Hartwig, E. Hoyer, D. Keefe, L.J. Laslett, L. Smith R. Bangerter, and J. Mark	Heavy Ion Induction Linacs for ICF (Presented at the 4th Amer. Nucl. Society Topical Meeting on Technology of Controlled Nucl. Fusion, Valley Forge, PA, Dec. 14-17, 1980)	9/80
HI-FAN-141	L.J. Laslett	Tune Depressions From σ_0=60 Deg. In a Symmetrical Fodo Lattice with small Occupancy factor (Large P)	1/26/81
HI-FAN-142	L.J. Laslett	Some Remarks and Results Concerning Multi-beam Focussing Electrodes that are not "Stiff" in their Connection to Ground	1/26/81
HI-FAN-143	R. Sah	HIF - Multiple Beam Arrays Workshop: 10/22/80 to 10/30/80 Technical Summary	1/27/81
HI-FAN-144 (LBL-12205)	A. Sternlieb, L. Smith, L.J. Laslett, J. Bisognano, and I. Haber	A Particle Simulation Code for Longitudinal Dynamics of Heavy Ion Beams	1/30/81
HI-FAN-145 (LBL-12107) Preprint	P.J. Channell, A.M. Sessler, and J.S. Wurtele	The Longitudinal Stability of Intense Non-Relativistic Particle Bunches in Resistive Structures (To be submitted for publication)	2/10/81
HI-FAN-146	J. Bisognano	An Overview of Possible Experiments on Existing Accelerators Relevant to RF Linac/Storage Ring HIF	3/3/81
HI-FAN-147	S. Rosenblum, Chet Pike	High Voltage Insulator Material Breakdown In Vacuum	3/4/81
HI-FAN-148A	L.J. Laslett	Initial Estimates of Pumping From a Multi-Electrode Array	3/11/81
HI-FAN-148B	L.J. Laslett	Pumping from a Multi-Electrode Array	3/11/81
HI-FAN-149	D. Keefe and W. Herrmannsfeldt	Multiple-Beamlet Heavy Ion Induction Linac	3/15/81
HI-FAN-150	L.J. Laslett	Information Intended to Relate the Matching Section to the Periodic Lattice of the Projected Single-Beam Transport Experiment	3/30/81
HI-FAN-150A	L.J. Laslett	Emittances Associated With Linearized Envelope Equations -- Sequel to HI-FAN-150	4/13/81
HI-FAN-151 (Eng. Note M5646)	E. Hoyer	Superconducting Quadrupole Model	4/2/81

HI-FAN-152	L.J. Laslett	Letter to Dr. R.S. MacKay, Princeton University	4/9/81
HI-FAN-153	D. Keefe	Letter to Dr. S. Rockwood, Los Alamos Scientific Laboratory	4/10/81
HI-FAN-154 (LBL-11750)	T.S. Wang and L. Smith	Transverse-Longitudinal Coupling in Intense Beams (Presented at the 1981 Particle Accelerator Conf., Washington, D.C., March 11 - 13, 1981)	4/19/81
HI-FAN-155 (LBL-11745)	A. Garren and G. Krafft	Focussing of Heavy Ion Beams on a Fusion Target (Presented at the 1981 Particle Accelerator Conf., Washington, D.C., March 11 - 13, 1981)	4/21/81
HI-FAN-156 (LBL-11741)	S. Chattopadhyay, A. Faltens, and L. Smith	Study of the Beam Breakup Mode in Linear Induction Accelerators for Heavy Ions (Presented at the 1981 Particle Accelerator Conf., Washington, D.C., March 11 - 13, 1981)	4/21/81
HI-FAN-157 (LBL-11751)	W. Chupp, A. Faltens, E. Hartwig, E. Hoyer, D. Keefe, C. Kim, M. Lampel, E. Lofgren, R. Nemetz, J. Shiloh, S.S. Rosenblum, M. Tiefenback, D. Vanecek, and W. Herrmannsfeldt	Operating Experience With a High Current Cs^{+1} Injector For Heavy Ion Fusion (Presented at the 1981 Particle Accelerator Conf., Washington, D.C., March 11 - 13, 1981)	4/21/81
HI-FAN-158	W. Herrmannsfeldt	High Intensity, Multi-Megajoule Heavy Ion Accelerator (A Plan for Research, Design, Development and Demonstration)	11/80

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